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Tutoring with Higher Mathematics and the Use of Technology

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Abstract

We discuss three approaches to the use of technology as a teaching and learning tool that we are currently implementing for a target group of about one hundred second level engineering mathematics students. Central to these approaches is the underlying theme of motivating relatively poorly motivated students to learn, with the aim of improving learning outcomes. The approaches to be discussed have been used to replace, in part, more traditional mathematics tutorial sessions and lecture presentations.

In brief, the first approach involves the application of constructivist thinking in the tertiary education arena, using technology as a computational and visual tool to create motivational knowledge conflicts or crises. The central idea is to model a realistic process of how scientific theory is *actually* developed, as proposed by Kuhn (1962), in contrast to more standard lecture and tutorial presentations. The second approach involves replacing procedural or algorithmic *pencil-and-paper* skills-consolidation exercises by software based tasks. Finally, the third approach aims at creating opportunities for higher order thinking via “on-line” exploratory or discovery mode tasks. The latter incorporates the *incubation period* method, as originally discussed by Rubinstein (1975) and others.

Introduction

In this work, we focus on the teaching of mathematics as a service subject to undergraduate engineering students. This presents certain challenges which seem to be more pronounced when compared with teaching mathematics to students from other degree programs. The key problem, we believe, appears to be one of motivation. An informal survey of lecturers and tutors in the engineering mathematics strand at QUT yields a recurring view, namely, that students from this group appear to have either a low intrinsic motivation to study mathematics or, equally of concern, a low perceived need to study mathematics as part of their professional training as future engineers.

If questions of course relevance can be reasonable put aside (we believe they can), it is then of some importance to consider why this is the case, and what we can do in educational terms to address this problem with a view to improving student learning outcomes.

With the preceding comments in mind, we discuss three computer based teaching and learning approaches here. In addition to producing technologically literate graduate engineers, one of the main attractions of adopting computer based methods (CBM) of presenting domain specific knowledge is that students generally seem to be more motivated to work on computers. In addition to its motivational value, The CBM appears to have other positive features. For example, there is some

evidence to suggest that students learn to be reflective in their thinking after using the CBM (Patterson & Smith, 1986). Moreover, the CBM appears to be pedagogically more effective in that it seems to allow for various learning styles. Indeed, students who are kinesthetic oriented, reflective, or visual learners can use their dominant learning styles (the literature indicates that student learning is more effective when they use their preferred learning styles). Further, while working on computers students have the opportunity to observe their peers (via screen displays) and thus effectively engaging in group discussion or cooperative learning (Smith, 1996; Webb, 1989). It can be argued that CBM also allows students to be more independent and thus take greater responsibility for their learning generally.

While there is some research evidence to suggest that students are motivated and also engaged in higher-order thinking when working on computers, there appears to be room for further work in this area, particularly in the tertiary education arena. Indeed, the computer based way of presenting learning materials has provided the impetus for tertiary educators to examine the effectiveness of this type of instruction in terms of whether the students are in fact acquiring the necessary skills that enhances their ability to problem solve and transfer knowledge. In their report on the use of technology in language learning, the National Board of Employment, Education and Training argued that, while there is a need for change in practice due to the influence of technology, the change is only warranted if there is evidence that learning is more effective (National Board of Employment Education and Training, NEET, 1996).

In following their view, we have implemented three different CBM approaches to teaching and learning which aim at increasing existing levels of motivation to study mathematics in our target group as a whole, with the ultimate aim of increasing student learning outcomes.

This paper is organised as follows. We begin by discussing why students in our target group are relatively less motivated than their peers, followed by a discussion of traditional tutorial formats and how we believe they need to change to address this problem. A discussion of the three approaches we have taken is then presented, followed by general comments and closing remarks about our experiences thus far.

Why aren't they Interested?

In general, understanding students' attitudes enables educators to adapt more appropriate strategies for learning, and in the present case it is interesting to speculate as to why undergraduate engineering students appear less motivated in their study of mathematics than their peers.

To this end, we consider the expectancy-value theory of motivation as a starting point (see e.g. Biggs & Moore, 1993), which asserts that motivation is the product of *likelihood of success* and *the perceived value/importance of the task*. We consider both factors in turn.

Firstly, with respect to likelihood of success, it is clear that currently the average mathematical preparation and ability of a student in our target group is less than was the case for the elite system of the past. The implication for a student from this group is that they are less likely to have developed a consistent sense of an "expectation of success" in their prior mathematical studies, which may undermine the development of any strong motivation for the task at hand. However, given that the average preparation and ability of students entering most degree programs has also

dropped, it is perhaps difficult to argue this as a primary cause for the perceived lack of motivation for mathematical studies in our targetted group.

With respect to the second factor of preceived value or importance, we note that in the former elite system, academically high achievers (the majority male) would often strategically choose “power knowledge” subjects such as higher maths and the “harder” sciences (e.g. physics, chemistry over biology, geology, etc.) in their pre-university studies, often with the underlying belief that such choices had the potential to maximise their material outcomes in adult life.

By way of contrast, in more recent times there seems to be a trend in a number of secondary education systems to actively encourage a broader view of secondary studies. The general aims of the Queensland secondary system, for example, appear to be predicated on the assumption that a wider category of knowledge should be celebrated, not merely knowledge which has been traditionally valued in previos era. We believe that an unintended spin-off of this is that the relative importance of high level mathematical training for those who intend to pursue careers in engineering is potentially understated. As a result, their motivation to study mathematics as part of their professional training may be potentially lower due to a less strongly felt “need to know” element.

Perhaps one of the more plausible reasons for the perceived lower motivation in our target group can be attributed to the link between self-concept and motivation, as discussed by de Charms (1968). He identified highly intrinsically motivated persons (which he called ‘origins’) as seeing themselves as the cause of their own behavior, as self-determining individuals, in charge of their lives, and having ownership over themselves and over what they do. Conversely, ‘pawns’ (as de Charms called them) are people who see themselves as being directed by other people more powerful than themselves, are not self-determining (i.e. they do what they believe others have decided for them), have little sense of ownership and are not easily motivated. In particular, de Charms concluded that students saw themselves as pawns as a result of the demands made upon them from outside. Simply put, de Charm’s self-concept theory essentially links the degree of motivation to the extent to how much an individual see themselves being controlled.

With regard to engineering maths subjects (and quite possibly any service subject) it is probable that while the student has actively chosen to pursue a degree in engineering, they have very little say over non-elective subjects within their chosen degree program. Consequently, a little bit of de Charm’s pawn emerges, and motivation for these subjects is potentially undermined.

While the main reasons for our students apparent lack of motivation may be ultimately difficult to determine, it is nevertheless clear that there exists a need to develop strategies which are more motivating than traditionally used approaches in the tertiary arena.

The mathematics tutorial

In order to initiate improvements to student learning outcomes, we envisage a number of changes to the ways mathematics tutorials have been conducted in the past. The typical tutorial we have in mind here is where students almost exclusively engage in individual pencil-and-paper skills-practice exercises. At the same time, the tutor tours, answering any student generated questions that may arise. The tutor, incidentally, while usually a reasonably skilled mathematician, often has very little teaching

experience or training, and their only reference point is the good or bad tutorials they themselves have experienced as undergraduates. The tutor is often “youngish”, and may have insufficient personal presence, self confidence or maturity to engage in high level tutor-student interaction. More often than not the tutor is poorly instructed about course content, objectives, emphasis and assessment, which virtually guarantees that the tutorial design can be little more than described above.

The disadvantages of the above are clear, but the following points are worth noting. For the traditional tutorial design to be of benefit, the student must in general be highly motivated, a high achiever (for which occasional access to a more highly skilled mathematician is sufficient to iron out difficulties), does not need a variety of learning styles to assimilate new material and is able to work individually through textbooks, notes and set exercises. In general, no mathematics related communication skills or other inter-personal skills are developed in this environment. It is hardly surprising, therefore, that in the past mathematicians were often viewed as ‘oddball’ or ‘geekish’ introverts! The system was in fact set up to select and breed them!

Clearly, we would argue that the tutor should play a far more active role to enhance student learning, especially in the first instance as a motivator via well established approaches such as displaying enthusiasm for the subject matter, communicating relevant ideas and information in a vibrant manner, and encouraging students to engage in the learning process, perhaps fundamentally via relationship building. The role of the tutor in the implementation of technology into tutorial sessions is also pivotal. We would argue that if one merely adds technology based tasks into a session which does little more than engage students in individual practice of required skills, then the potential benefits will be less than more imaginative, research guided approaches.

With these general remarks in mind, we now briefly describe three approaches which use technology to enhance student learning outcomes.

Approach One

The first approach we have investigated involves the application of constructivist thinking in the tertiary education arena, something which does not appear to be widespread despite its growing acceptance in the secondary education sphere as part of effective pedagogical practice.

Typically, the approach involves the use of mathematical software in a supporting role in the presentation and exposition of new material in a tutorial style session (which in itself is nothing new), but with the main focus being to provide learning experiences which are essentially constructivist in nature. The idea is to exploit the visual and algebraic capabilities of mathematical software to highlight non-intuitive mathematical results in ways which promote a re-evaluation of the student’s current knowledge base, and motivate the student to extend their mathematical knowledge to accommodate the newly observed mathematical properties or results. In summary, technology is used as a computational and visual tool to create motivational knowledge conflicts or crises. The central idea is to model a realistic process of how scientific theory is *actually* developed, as proposed by Kuhn (1962), in contrast to more standard presentations which are often experienced in lectures or large tutorials where student numbers are high.

In our talk, we shall discuss a successful case study involving the presentation of theory of polynomial and cubic spline interpolation. The students already had prior

knowledge of interpolation, and had invariably 'constructed' the view that the use of higher order polynomials *should* lead to higher quality interpolation, in the absence of any exposure to theory which suggests otherwise. The latter is a seemingly harmless generalisation constructed most probably from their exposure to other modelling exercises. However, the presentation of a number of carefully constructed counter-intuitive examples clearly demonstrated that their currently held view is false. Indeed, on delivering our presentation of the theory from the approach described above, we were able to arouse a classic response to the 'crisis'. We observed the characteristic stages (as described by Kuhn) of knowledge conflict, disbelief, and resistance to change. Finally, acceptance and motivation to understand extensions to the theory in order to resolve the knowledge 'crisis' was observed in the students.

Approach Two

The second approach we have investigated is where mathematical software is used in computing laboratory style sessions, where the student is set tasks which complement theory which has been previously presented in lectures or similar large group plenary formats. In this approach the main focus is on the consolidation of new knowledge via the implementation of hands-on examples, typically the computation of routine, algorithmic or procedural mathematical problems using symbolic algebra packages, spreadsheets, and similar mathematical software. This approach is essentially aimed at replacing existing tutorial sessions where pencil-and-paper skills-consolidation exercises are typically set for student work. To increase the pedagogical benefit, students were also required to write up a report of their experience, which involved a discussion of theoretical as well as procedural aspects of the set task. Essentially the implementation here mirrors existing good practice in science and other discipline areas.

In our talk we shall discuss a case study where an exercise on Romberg integration was implemented using a spreadsheet. To enhance the expectation of success, instructions to 'code-up' the task were simply and prescriptively given so that students had little difficulty in completing the exercise. In fact, failure to enter data correctly as per instructions invariably led to immediate feedback from the software, and the final answer was given so that students had a clearly defined endpoint to aim for.

We believe that some of the advantages of this approach are that students were exposed to using a spreadsheet as a mathematical/computational engine, the exercise gave students the opportunity to consolidate 'procedural' knowledge of the theory (i.e. how it can be used to solve specific problems), and the task was both instructional but at a level of difficulty for which the majority of students could expect to complete it without undue problems. In addition, the report demanded that they subsequently extend their understanding by writing an overview on both the 'how' (procedural) and the 'why' (conceptual/theoretical) of the Romberg method, in addition to selected pencil-and-paper exercises.

Approach Three

Finally, the third approach aims at creating opportunities for higher order thinking via "on-line" exploratory or discovery mode tasks. This approach incorporates the *incubation period* method, as originally presented by Rubenstein (1975) with regard to expert problem solving and creativity. After examining a number of experts' knowledge development, creative abilities and achievements, Rubenstein suggested that creativity involves the linking and "connectiveness" of knowledge (that is, cognitive connection building). He argued that such a process usually occurs after an "incubation" period. It seems that applying this incubation period method to the teaching of difficult higher level concepts of mathematics may be a useful teaching method. For example, the learners may need to learn concretely, visually, and symbolically first and then after an incubation period re-examine the content and/or procedures in a more formal manner (Piaget, 1968, Tall, 1991). In this way, the learners can reflect on their work and examine the content more critically. According to constructivist educational theorists such a process may facilitate the connectiveness of knowledge through the linking of concepts and procedures into a logical/coherent cognitive structure (Clements & Battista, 1990; English, 1997; Neiss, 1993; Sternberg, 1988).

With the preceding comments in mind, we investigated the effectiveness of a novel way of teaching Fourier series to second year engineering mathematics students. This topic is an important one as Fourier series has a number of applications in mathematics. However, anecdotal evidence suggests that students find the complexity the Fourier series difficult to deal with, and it would seem that any suggestions for improvements in the teaching of this topic would be appreciated by many tertiary mathematics educators.

In the implementation of our third approach, a computer based on-line method was used to provide students with pre-lecture laboratory experience. The laboratory was not simply an on-line visual based tutorial but rather a combination of hands-on, visual and written/research work. In this manner we aimed to examine attitudes, beliefs and patterns in thinking to decipher the nature of thinking undergone during the tutorial (Schoenfeld, 1985; Tularam, 1998). The Fourier series program was designed to examine whether, given the opportunity, students self-engage their higher mental faculties of metacognitive and critical thinking while working on-line. The questions posed in the tutorials may have created some tension and conflict in students' minds and to resolve such conflicts, students needed to move away from the computers and engaging in written, reflective and/or critical thinking. Indeed, this "movement away" from the computer to written or other reflective research work was an important aspect of the self-learning laboratory program. In such actions the students' thinking can be explored to determine whether they were indeed engaging their higher faculties (Flavell, 1987).

Concluding Remarks

In this paper, we have discussed the need for teaching and learning strategies which aim to raise motivation in engineering mathematics students. We have discussed three technology based approaches which we are currently implementing in tutorial settings to address this problem. At the present stage, we have clear evidence that students find these alternative approaches more acceptable than more traditional tutorial sessions, but nonetheless, there are a few areas that need further investigation. In particular, if an approach can be established as more motivational, it remains to demonstrate the pedagogical benefit in terms of student learning outcomes. For example, do the students who experience technology based teaching gain metacognitive/reflective and critical thinking skills while working on computers in an "on-line" manner? While there is some evidence to suggest that students do gain the necessary higher-order thinking skills there needs to be more work done in this area. Indeed, the new way of presenting learning materials has provided the impetus for educators to examine the effectiveness of computer based instruction in terms of whether the students are in fact acquiring the necessary skills that enhances students' ability to transfer knowledge.

Report on Tutoring Conference 24th/Sept/98

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Funding: Registration paid by School of Mathematical Sciences

Summary

This one day conference was held at UQ on the 24th of September 1998. Two papers were accepted and will appear in the proceedings (to be published on the WWW). The papers describe innovative teaching strategies which have been implemented in the Engineering Mathematics strand here at QUT, both in the lecture and tutorial setting. These strategies are guided by the research literature on teaching and learning, and focus primarily on the use of technology as motivational devices to enhance student learning outcomes in the tertiary arena.

Publications

Kelson, N.A., & Tularam, A. Tutoring with Higher Mathematics & the use of Technology

Tularam, A. Individual Differences in Learning Styles
